Clinical Sports Medicine Update

Outcome After Surgical Repair of Proximal Hamstring Avulsions

A Systematic Review

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Background: At the present time, no systematic review, including a quality assessment, has been published about the outcome after proximal hamstring avulsion repair.

Purpose: To determine the outcome after surgical repair of proximal hamstring avulsions, to compare the outcome after acute (≤4 weeks) and delayed repairs (>4 weeks), and to compare the outcome after different surgical techniques.

Study Design: Systematic review and best-evidence synthesis.

Methods: PubMed, CINAHL, SPORTdiscus, Cochrane library, EMBASE, and Web of Science were searched (up to December 2013) for eligible studies. Two authors screened the search results separately, while quality assessment was performed by 2 authors independently using the Physiotherapy Evidence Database (PEDro) scale. A best-evidence synthesis was subsequently used.

Results: Thirteen studies (387 participants) were included in this review. There were no studies with control groups of nonoperatively treated proximal hamstring avulsions. All studies had a low methodological quality. After surgical repair of proximal hamstring avulsion, 76% to 100% returned to sports, 55% to 100% returned to preinjury activity level, and 88% to 100% were satisfied with surgery. Mean hamstring strength varied between reporting studies (78%-101%), and hamstring endurance and flexibility were fully restored compared with the unaffected side. Symptoms of residual pain were reported by 8% to 61%, and reported risk of major complications was low (3% rerupture rate). No to minimal difference in outcome was found between acute and delayed repair in terms of return to sports, patient satisfaction, hamstring strength, and pain. Achilles allograft reconstruction and primary repair with suture anchors led to comparable results.

Conclusion: The quality of studies included is low. Surgical repair of proximal hamstring avulsions appears to result in a subjective highly satisfying outcome. However, decreased strength, residual pain, and decreased activity level were reported by a relevant number of patients. Minimal to no differences in outcome of acute and delayed repairs were found. Limited evidence suggests that an Achilles allograft reconstruction yields results comparable with primary repair in delayed cases where primary repair is not possible. High-level studies are required to confirm these findings.

Keywords: hamstring; avulsion; rupture; biceps femoris; semitendinosus; semimembranosus; hamstring origin; ischial tuberosity

Hamstring avulsions account for 3% to 11% of all hamstring injuries in predominantly elite athletic populations.[21,27] Both athletes and middle-aged individuals are affected by proximal hamstring avulsions,[10] typically during sports participation or slip and fall accidents with forced hip hyperflexion and ipsilateral knee extension, as well as forced eccentric contraction of the hamstring muscle complex.[‖] Significant functional impairment can result from these injuries, and this can be career threatening for athletes.[5,9,11,13,18,25] There is a lack of consensus on indication and timing of surgery. Some authors state that surgical treatment should be reserved for displaced bony

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‖References 8, 11, 18, 26, 32, 33, 38, 44, 46, 54.

avulsions, proximal tendinous avulsions involving all 3 tendons, proximal 2-tendon avulsions with retraction of >2 cm, or persisting pain.[10,11,19,23] When it comes to timing of surgery, delayed surgical repair (>4 weeks) is generally considered more challenging,[1,2,7,54] while it is suggested that the outcome may be less favorable compared with acute repair (≤4 weeks). Timely assessment (preferably within 2 days after trauma[24]) has been proposed to prevent delay in diagnosis and treatment.

After surgery, range of motion in hip and knee is restricted for about 4 to 6 weeks followed by a phased progressive rehabilitation program that varies considerably between reports. Generally, the rehabilitation programs start with range of motion exercises and gait training, followed by progressive hamstring and core-strengthening exercises. Finally, sport-specific exercises are included before return to (athletic) activities.[¶]

Nonoperative management of proximal hamstring avulsions mainly comprises rest, icing, and exercises with a gradual return to (athletic) activities[10] and appears to lead to conflicting results. Sallay et al[45] presented 12 cases, of which 58% returned to sports at a lower level, while Malliaropoulos et al[36] presented 11 high-level athletes with a 100% return to sports rate.

An interesting systematic review in 2011[22] concluded that surgical treatment of proximal hamstring avulsions is preferred over nonoperative treatment in terms of subjective clinical outcomes, strength, endurance, and return to sports. The authors reported a return to sports rate at preinjury level of 79% (236/298), 82% in the surgical repair group (234/284), compared with 14% in the nonoperatively treated group (2/14). They concluded that acute surgical repair leads to superior results compared with delayed repair in terms of subjective clinical outcomes, strength, endurance, return to sports at preinjury level (96% vs 75%), and risk of major complications and rerupture. However, this review did not involve any quality assessment of the studies included, and therefore there is a risk of bias.

The main purpose of this review was (1) to determine the outcome after surgical repair of proximal hamstring avulsions, (2) to compare the outcome of acute (≤4 weeks) and delayed (>4 weeks) repair, and (3) to compare the outcome of different surgical techniques. We hypothesized that (1) surgical repair of proximal hamstring avulsions leads to high patient satisfaction and allows for return to sports at the preinjury level with good recovery of hamstring function, (2) acute repair does better than delayed repair since the latter is considered more technically challenging, and (3) alternative surgical repair techniques yield less satisfactory results since they are required in more complex cases.

METHODS

Search Strategy

A systematic literature search was performed up to December 2013 in the databases of Medline via PubMed, CINAHL via EBSCOhost, SPORTdiscus via EBSCOhost, Cochrane Library, EMBASE via OvidSP, and Web of Science. Two keywords (*hamstring* and *avulsion*) and related synonyms were used. Within each keyword category, the different synonyms were combined using the Boolean command OR, and categories were linked with the Boolean command AND (see the Appendix, available online at http://ajsm.sagepub.com/supplemental).

Eligibility Criteria

Original articles were included if (1) diagnosis of a proximal avulsion of the biceps femoris, semimembranosus, or semitendinosus muscle or a combination of either was confirmed by magnetic resonance imaging (MRI) or ultrasound; (2) the therapeutic approach was well described; and (3) full texts were available in English or Dutch. Case reports, imaging reviews, anatomic/histologic studies, surgical technique reports, animal studies, studies with less than a mean 12 months of follow-up, studies with fewer than 5 participants, and studies reporting outcomes other than clinical endpoints were excluded.

Study Selection

Two reviewers (A.D.M. and G.R.) independently assessed potential eligible studies identified by the search strategy. Titles and abstracts were assessed by applying the eligibility criteria, and full texts of potentially relevant studies were subsequently obtained. If the title and abstract did not provide sufficient information to determine whether eligibility criteria were met, the study was included for full-text selection. The full texts were read independently by the 2 reviewers and assessed for eligibility. If no consensus was reached, a third author (G.M.K.) was available to make the final decision regarding eligibility but was eventually not necessary. We performed additional citation tracking by screening the reference lists of the eligible studies.

Data Extraction

Data from the original articles were extracted using a standardized extraction form, including study design, number of participants, mean age, mean duration of follow-up, timing of surgery, surgical method of reattachment, postoperative program, surgical outcome, and complications. Whenever outcome was reported for more than one point in time during follow-up, values of the last recorded follow-up were used.

Quality Assessment

Quality assessment of the included studies was performed by 2 authors independently (V.G. and J.L.T.) using the Physiotherapy Evidence Database (PEDro) scale (Table 1).[14,35] If no consensus was reached, the independent opinion of a third reviewer (A.D.M.) was decisive. The PEDro scale scores 11 items (eligibility criteria, random allocation, concealed allocation, similarity at baseline, participant blinding, therapist blinding, assessor blinding, >85% follow-up for at least 1 key outcome, intention-to-

[¶]References 4, 5, 8, 11, 18, 26, 32, 38, 44.

TABLE 1
Physiotherapy Evidence Database (PEDro) Scale

Item PEDro Scale	Description
1	Eligibility criteria were specified.
2	Participants were randomly allocated to groups.
3	Allocation was concealed.
4	The groups were similar at baseline regarding the most important prognostic indicators.
5	There was blinding of all participants.
6	There was blinding off all therapists who administered the therapy.
7	There was blinding of all assessors who measured at least 1 key outcome.
8	Measures of at least 1 key outcome were obtained from more than 85% of the participants initially allocated to groups.
9	All participants for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least 1 key outcome were analyzed by "intention to treat."
10	The results of between-group statistical comparisons are reported for at least 1 key outcome.
11	The study provides both point measures and measures of variability for at least 1 key outcome.

treat analysis, between-group statistical comparison for at least 1 key outcome, and point and variability measures for at least 1 key outcome) as either present or absent. The final score is the number of positive answers on questions 2 to 11. The first statement relates to the external validity of the study and is not considered in the final quality score. The PEDro scale has been validated,[14] and its reliability is rated fair to good.[35] We considered a PEDro score of ≥6 to represent a high-quality study and a score of ≤5 a low-quality study.[17]

Best-Evidence Synthesis

Because of the heterogeneity of outcome measures, a best-evidence synthesis[50] was used instead of a meta-analysis. The results of the quality assessments of the individual studies were used to classify the level of evidence.[53] This qualitative analysis was performed with 5 levels of evidence based on the quality and results of the included studies:

1. Strong evidence: provided by 2 or more high-quality studies and by generally consistent findings in all studies (≥75% of the studies reported consistent findings)
2. Moderate evidence: provided by 1 high-quality study and/or 2 or more low-quality studies and by generally consistent findings in all studies (≥75% of the studies reported consistent findings)
3. Limited evidence: provided by only 1 low-quality study
4. Conflicting evidence: inconsistent findings in multiple studies (<75% of the studies reported consistent findings)
5. No evidence: when no studies could be found

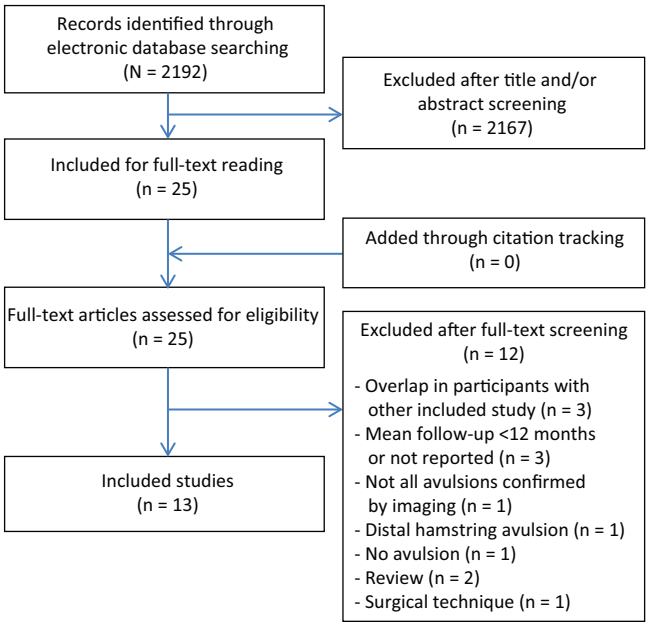

Figure 1. Flowchart of study selection.

RESULTS

References

The literature search in the selected databases yielded 2192 records. After deleting duplicates and applying the eligibility criteria to the titles and abstracts, 25 potentially relevant studies were included for the full-text review. Full-text articles were subsequently obtained and eligibility criteria were applied, leading to the inclusion of 13 original studies (Figure 1).[#] Citation tracking did not add any studies.

Quality Assessment

The quality assessment scores of the studies included are shown in Table 2. All included studies were scored as low-quality, which was mainly attributable to the lack of randomization and controls.

Outcome After Surgical Repair

The 13 original studies retrieved from our systematic search with a total of 387 participants (235 male, 152 female) involved 11 case series (8 retrospective,[4,8,11,33,38,44,46,49] 1 prospective,[26] 2 not further specified[5,54]), 1 cohort study,[18] and 1 case-control study[32] that were conducted among different study populations and included different outcome measures (questionnaire, patient satisfaction, pain, functional outcome scales, imaging, return to sports, return to preinjury activity level, hamstring flexibility, strength and endurance). There were no studies with control groups of nonoperatively treated proximal hamstring avulsions. The

[#]References 4, 5, 8, 11, 18, 26, 32, 33, 38, 44, 46, 49, 54.

TABLE 2
Quality Assessment (PEDro Scale) of the Included Studies[a]

	Item PEDro Scale											
Study	1	2	3	4	5	6	7	8	9	10	11	Total Score
Birmingham et al (2011)[4]	+	–	–	–	–	–	–	–	+	+	+	3/10
Brucker and Imhoff (2005)[5]	–	–	–	–	–	–	–	+	+	+	+	4/10
Chahal et al (2012)[8]	+	–	–	–	–	–	–	+	+	+	+	4/10
Cohen et al (2012)[11]	–	–	–	–	–	–	–	–	+	–	+	2/10
Folsom and Larson (2008)[18]	–	–	–	–	–	–	–	+	+	–	+	3/10
Konan and Haddad (2010)[26]	–	–	–	–	–	–	–	+	+	–	+	3/10
Lefevre et al (2013)[31]	+	–	–	–	–	–	–	+	+	–	+	3/10
Lempainen et al (2006)[33]	+	–	–	–	–	–	–	+	+	–	+	3/10
Mica et al (2009)[38]	–	–	–	–	–	–	–	+	+	–	–	2/10
Sallay et al (2008)[44]	+	–	–	–	–	–	–	+	+	–	+	3/10
Sarimo et al (2008)[46]	–	–	–	–	–	–	–	+	+	–	–	2/10
Skaara et al (2013)[49]	+	–	–	–	–	–	–	+	+	+	+	4/10
Wood et al (2008)[54]	+	–	–	–	–	–	–	+	+	–	+	3/10
Mean												3/10 ± 0.7

[a]PEdro, Physiotherapy Evidence Database.

outcome measures and characteristics of the included studies are shown in Table 3. Table 4 shows the best-evidence synthesis.

Return to Sports. Six studies (124 participants) reported the return to sports rate as an outcome measure.[4,8,11,18,26,32] Surgical repair resulted in a return to sports rate of 76% to 100% (Figure 2). This group includes 7 elite athletes,[8,11,18,32] 10 (semi)professional athletes,[26] 12 athletes who participated in competitive sports, and 6 high-level recreational athletes (sports participation ≥3 times/wk). The remaining athletes were recreational. In this group, 3 of 4 (75%) elite athletes[8,11,18] were able to return to preinjury level. Lefevre et al[32] pooled the elite and competitive athletes and reported that 12 of 15 (80%) returned to sports at the same level. Konan and Haddad[26] pooled the semiprofessional and professional athletes, of whom 9 of 10 (90%) returned to sports. The athlete who did not return to sports did so as a personal choice.

Level of Activity. Eight studies (235 participants) reported the return to a preinjury activity level rate as an outcome measure.[5,8,32,33,38,46,49,54] This was either level of activity in their field of sports or activities of daily life. Surgical repair resulted in a return to a preinjury activity level rate of 55% to 100% (Figure 2). Eighteen of 22 (82%) elite athletes in this group were able to return at a preinjury level at a minimal follow-up of 6 months.[5,8,33,54]

Tegner activity scale scores (range 0-10, where a higher score indicates a higher activity level) before injury (6; range, 4-10) and after recovery (6; range, 3-10) were equivalent, as reported by Lefevre et al.[32] Similarly, Chahal et al[8] used this scale to assess level of activity after injury and after recovery and found equivalent scores.

Cohen et al[11] used the Marx activity scale score (range 0-16, where a higher score indicates a higher activity level) and reported an average of 10 (range, 1-16). Using a custom version of this scale, they reported maximum scores (score of 20) in the acute group and 19 (range, 12-20) in the delayed group. Lefevre et al[32] reported a University of California at Los Angeles activity scale (range 1-10, where a higher score indicates a higher activity level) score of 9.1 ± 1.3 before injury and 8.7 ± 1.7 at final follow-up ($P = .03$).

Patient Satisfaction. Eight studies (198 participants) reported patient satisfaction.[5,8,11,18,26,32,44,49] Good-to-excellent patient satisfaction ranged from 88% to 100% (Figure 2). Birmingham et al[4] used a subjective questionnaire to evaluate patient satisfaction and rated the results excellent in 18 cases (78%), good in 4 (17%), and fair in 1 (4%). Using the Single Assessment Numeric Evaluation, Chahal et al[8] concluded that all patients (13/13) were extremely satisfied with the surgery performed.

Pain. Seven studies (203 participants) used pain as an outcome measure.[4,8,11,18,32,44,49] Residual symptoms of pain were reported by 8% to 61% of patients (Figure 2). We included reports of daily pain (8%-20%),[18,44] pain during activity (17%-39%),[4,49] or pain with prolonged sitting (9%-61%).[4,11,32] Chahal et al[8] reported a mean visual analog scale score (range 0-10, where a higher score indicates more pain) of 1.3 ± 1.9 (range, 0-5), which was classified as minimal to no pain.

Functional Outcome Scales. Sarimo et al[46] used a grading system based on residual symptoms and level of activity to grade the outcome of surgery. Of 41 cases, results were excellent in 19 (46%), good in 10 (24%), moderate in 5 (12%), and poor in 7 (17%). Similarly, in 48 cases, Lempainen et al[33] achieved excellent results in 33 cases (69%), good in 9 (19%), fair in 4 (8%), and poor in 2 (4%).

Chahal et al,[8] Cohen et al,[11] and Skaara et al[49] reported high scores on the Lower Extremity Functional Scale (LEFS; range, 0-80, where a higher score indicates less functional impairment): 75 ± 7.8 (range, 59-80), 75 (range, 50-80), and 71 ± 10 (range, 47-80), respectively. A custom version of this scale was used by Cohen et al,[11] who reported separate scores for their acute and delayed group: 71 (range, 48-80) and 71 (range, 47-80), respectively.

TABLE 3
Study Characteristics[a]

Study	Study Design (Mean Duration of Follow-up)	Participants, n (Acute/Delayed Repair), Mean Age, Sex, and Type of Athlete	Surgical Technique	Outcome Measure and Outcome[b]
Birmingham et al (2011)[4]	Retrospective case series (43 mo)	N = 23 (9/14); age = 46 y; sex = 15 M/8 F; type = NR	Reattachment with suture anchors	**Subjective questionnaire:** Results excellent in 18 cases, good in 4, and fair in 1 **RTS:** 21/23 **Pain:** 14/23 pain with prolonged sitting, 4/23 pain during activity **Hamstring strength:** Manual: 5/5 hamstring and quadriceps strength bilaterally; isokinetic: R = L, A = D; H/Q: R = L, A = D **Endurance:** R = L
Brucker and Imhoff (2005)[5]	Case series (33 mo)	N = 8 (6/2); age = 40 y; sex = 6 M/2 F; type = 1 elite athlete, 7 recreational athletes	Reattachment with suture anchors	**Patient satisfaction:** 8/8 satisfied **RTPA:** Acute: 5/6; delayed: 2/2 **Hamstring flexibility:** R = L **Hamstring strength:** Isokinetic: R = L, A = D
Chahal et al (2012)[8]	Retrospective case series (37 mo)	N = 13 (NR); age = 45 y; sex = 8 M/5 F; type = 1 elite athlete, 10 recreational athletes	Reattachment with suture anchors	**Patient satisfaction:** 13/13 extremely satisfied (SANE) **RTS:** 11/11 **RTPA:** 6/11 **Pain:** Mean VAS, 1.3 ± 1.9 (range, 0-5) **LEFS:** Mean, 75 ± 7.8 (range, 59-80) **HHS:** Mean, 91 ± 14 (range, 67-100) **Hamstring strength:** Isokinetic: 78% ± 6.1% (range, 74%-88%) of contralateral limb **Hamstring flexibility:** R = L **MRI examination (12/13):** 12/12 successful reattachment; 5/12 grade 0 atrophy, 5/12 grade 1 atrophy, 2/12 grade 2 atrophy of hamstring muscles of the affected leg **TAS:** No significant difference between preoperative and postoperative situation
Cohen et al (2012)[11]	Retrospective case series (33 mo)	N = 52 (40/12); age = 48 y; sex = 26 M/26 F; type = 1 elite athlete, recreational athletes	Reattachment with suture anchors	**Patient satisfaction:** 51/52 satisfied **RTS:** 23/23 (7/23 return to other sports) **Pain:** 48% pain with prolonged sitting **LEFS:** Mean, 75 (range, 50-80; A = D) **MAS:** Mean, 10 (range, 1-16; A = D)
Folsom and Larson (2008)[18]	Cohort study (20 mo)	N = 26 (21/5) (1 lost to follow-up); age = 44 y; sex = 12 M/14 F; type = 2 elite athletes, 6 high-level recreational athletes, 17 recreational athletes	Reattachment with suture anchors (21 acute, 1 delayed); Achilles tendon allograft reconstruction (4 delayed)	**Patient satisfaction:** Acute: 19/20 satisfied; delayed: 5/5 satisfied **RTS:** Acute: 15/20; delayed: 4/5 **Pain:** No daily pain in 80%, A = D **Hamstring strength:** Isokinetic: A = D; H/Q: A = D **Hamstring flexibility:** Symmetric ROM of hips and knees, A = D
Konan and Haddad (2010)[26]	Prospective case series (12 mo)	N = 10 (9/1); age = 29 y; sex = 8 M/2 F; type = 10 (semi)professional athletes	Reattachment with suture anchors	**Patient satisfaction:** 10/10 satisfied **RTS:** 9/10 **Hamstring strength:** Peak torque 83% vs contralateral side (range, 47%-118%)
Lefevre et al (2013)[31]	Case-control study (27 mo)	N = 34 (34/0); age = 39 y; sex = 25 M/9 F; type = 3 elite athletes, 12 competitive athletes, 17 recreational athletes	Reattachment with suture anchors	**Patient satisfaction:** 26/34 very satisfied, 4 satisfied, and 4 moderately satisfied **RTS:** 32/32 **RTPA:** 27/32 **Pain:** 3/34 mild pain with prolonged sitting **UCLA score:** 9.1 ± 1.3 before injury and 8.7 ± 1.7 at final follow-up (significant difference) **TAS:** 6/10 (range, 4-10) before injury and 6/10 (range, 3-10) at final follow-up **Hamstring strength:** Isokinetic: mean 93% ± 18% (90 deg/s), 94% ± 16% (180 deg/s), and 101% ± 13% (240 deg/s) vs contralateral limb **MRI examination:** Tendon healed in 34/34
Lempainen et al (2006)[33]	Retrospective case series (36 mo)	N = 47 (5/42); age = 33 y; sex = 32 M/15 F; type = 13 elite athletes, 15 competitive athletes, 19 recreational athletes	Reattachment with suture anchors (43); reattachment directly to periosteal bone/proximal tendon stump (5)	**Functional result (based on residual symptoms and level of activity):** Results excellent in 33/48 cases, good in 9/48, fair in 4/48, and poor in 2/48 **RTPA:** 41/47
Mica et al (2009)[38]	Retrospective case series (32 mo)	N = 6 (6/0); age = 59 y; sex = 3 M/3 F; type = middle-aged and elderly patients	Reattachment with suture anchors	**RTPA:** 6/6 **HHS:** Mean, 97 (range, 86-100, R = L, no difference vs status before injury) **MRI examination:** Tendon healed in 6/6
Sallay et al (2008)[44]	Retrospective case series (53 mo)	N = 25 (18/7); age = 44 y; sex = 13 M/12 F; type = NR	Reattachment with suture anchors	**Patient satisfaction:** 25/25 satisfied **Pain:** 92% of patients had no to minimal daily pain **Hamstring strength:** Isokinetic: 98% strength return at >12 mo (range, 72%-176%)
Sarimo et al (2008)[46]	Retrospective case series (37 mo)	N = 41 (14/27); age = 46 y; sex = 21 M/20 F; type = 2 competitive athletes, 27 recreational athletes	Reattachment with suture anchors (14 acute, 26 delayed); iliotibial tract autograft reconstruction (1 delayed)	**Functional result (based on residual symptoms and level of activity):** Results excellent in 19/41, good in 10/41, moderate in 5/41, and poor in 7/41. Good to excellent results had a mean delay of 2.4 mo. Poor to moderate results had a mean delay of 12 mo. Significant difference in results between a 0- to 3-mo delay and 3- to 6-mo and >6-mo delay. No significant difference between a 3- to 6-mo and >6-mo delay **RTPA:** 22/29

(continued)

TABLE 3
(continued)

Study	Study Design (Mean Duration of Follow-up)	Participants, n (Acute/Delayed Repair), Mean Age, Sex, and Type of Athlete	Surgical Technique	Outcome Measure and Outcome[b]
Skaara et al (2013)[49]	Retrospective case series (30 mo)	N = 31 (28/3); age = 51 y; sex = 16 M/15 F; type = 5 competitive athletes, 26 recreational athletes	Reattachment with suture anchors	**Patient satisfaction:** 29/31 satisfied **RTPA:** 18/31 **Pain:** 39% pain/limitations during activity **LEFS:** 71 ± 10 (range, 47-80) **Hamstring strength:** Significant difference in peak torque vs contralateral limb
Wood et al (2008)[54]	Case series (24 mo)	N = 71 (NR); age = 40 y; sex = 50 M/21 F; type = 7 elite athletes	Reattachment with suture anchors	**RTPA:** 57/71 RTPA **Hamstring strength:** 84% isotonic strength vs contralateral side (range, 43%-122%). Significant difference in strength between acute (<3 mo) and chronic in case of retraction **Endurance:** 89% isotonic endurance vs contralateral side (range, 26%-161%). Significant difference in endurance between acute (<3 mo) and chronic in case of retraction

[a]F, female; HHS, Harris hip score; H/Q, hamstring-to-quadriceps ratio; LEFS, Lower Extremity Functional Scale; M, male; MAS, Marx activity scale; MRI, magnetic resonance imaging; NR, not reported; ROM, range of motion; RTPA, return to preinjury activity level; RTS, return to sports; SANE, Single Assessment Numeric Evaluation; TAS, Tegner activity scale; UCLA score, University of California at Los Angeles 10-point scale; VAS, visual analog scale.

[b]A = D indicates no statistically significant difference between acute and delayed repair; R = L indicates no statistically significant difference vs contralateral leg.

Chahal et al[8] and Mica et al[38] reported high scores on the Harris hip score (range 0-100, where a higher score indicates less functional impairment, deformity, and pain): 91 ± 14 (range, 67-100) and 97 (range, 86-100), respectively.

Strength Testing. Nine studies reported hamstring strength measurements.** Mean isokinetic strength return ranged from 78% to 101% compared with the unaffected side[4,5,8,18,26,32,44,49] (Figure 2). Birmingham et al[4] reported no significant difference in isokinetic hamstring strength or endurance of the operated leg compared with the contralateral leg. Lefevre et al[32] and Sallay et al[44] reported near-equivalent isokinetic hamstring strength, while Brucker et al[5] and Konan et al[26] reported a deficit in peak torque, with hamstring strength of 88% (not statistically significant) and 83%, respectively. Chahal et al[8] found isokinetic hamstring strength of 78%, and Skaara et al[49] reported significant difference in peak torque (84%) compared with the contralateral leg. Wood et al[54] reported mean isotonic hamstring strength of 84% and mean hamstring endurance of 89% compared with the contralateral leg.

Hamstring-to-quadriceps ratio[4] and hamstring flexibility[5,8,18] did not differ significantly when compared with the contralateral leg.

MRI Examination. Three studies[8,32,38] showed healing of the reattached tendons in all 52 participants (at a follow-up of at least 6 months,[32] a mean of 36 months,[8] and 32 months[38]). There were 5 cases in which grade 1 atrophy of the hamstring muscles of the affected leg was found on MRI, 2 cases with grade 2 atrophy, and 3 cases with mild tendinopathy[8].

Complications. Several postoperative complications were reported. In a total of 387 participants, reoperation was needed in 10 cases (3%)[5,18,33,46,54] (Figure 2). There were 3 cases with a deep vein thrombosis (1%).[11,44,46] Eleven patients had a wound infection (3%; 1 deep infection[18] and 10 superficial infections[18,33,46,49,54]). There was mention of evacuation/drainage of 1 postoperative hematoma,[32] 1 seroma,[46] and 1 patient with hypertrophic scarring.[33] Stiffness of the operated leg was reported in 12 patients (3%).[8,44] Symptoms of numbness/tingling in the incisional area were reported in 34 patients (9%),[4,11] in the posterior thigh and below the knee in 30 patients (8%),[4,8,11,26,46,49] and in the affected leg (area not specified) in 2 patients (1%).[44] Symptoms of sciatica were reported in 5 patients (1%).[4,54] One patient developed complex regional pain syndrome, with severe pains and muscle spasms.[18]

Outcome After Acute and Delayed Repair

Six studies made a distinction between acute and delayed repair[4,5,11,18,46,54] (Table 4). Acute repair was defined as surgical treatment ≤4 weeks after injury. Delayed repair was defined as surgical treatment >4 weeks after injury.

Return to Sports. Only 2 studies mentioned the return-to-sports (RTS) rate separately for acute and delayed repairs.[5,18] In the acute repair group, 75% to 83% of patients returned to sports versus 80% to 100% in the delayed repair group. Of the 3 elite athletes,[5,18] 2 (67%; 1 acute and 1 chronic repair) were able to return to sports at their previous level after a full recovery.[18]

Patient Satisfaction. The only study that made a distinction between patient satisfaction of the acute and delayed repair group was that of Folsom and Larson.[18] In this study, 19 of 20 (95%) patients in the acute repair group were satisfied with the performed surgery versus 5 of 5 (100%) patients in the delayed repair group. However, although Brucker and Imhoff[5] did not distinguish between patient satisfaction of the acute and delayed group, all patients were satisfied, implying no difference between acute and delayed surgery groups.

**References 4, 5, 8, 18, 26, 32, 44, 49, 54.

TABLE 4
Best-Evidence Synthesis for Timing and Technique of Surgery[a]

	Outcome Measure	High Quality	Low Quality (Study)[b]	Best-Evidence Synthesis[c]
Timing of surgery	Patient satisfaction		= (5, 18)*	Moderate
A: Acute repair (≤4 weeks)	Pain		= (18)	Limited
D: Delayed repair (>4 weeks)	Return to sports		d (5, 18)*	Moderate
	Hamstring flexibility		= (18)	Limited
	Hamstring strength		= (4, 5, 18)	Moderate
	Hamstring-to-quadriceps-ratio		= (4, 18)	Moderate
	LEFS		= (11)	Limited
	Marx activity scale		= (11)	Limited
Surgical technique	Patient satisfaction		= (18)*	Limited
R: Achilles tendon allograft reconstruction	Return to sports		= (18)*	Limited
P: Primary repair with suture anchors	Pain		= (18)	Limited
	Hamstring flexibility		= (18)	Limited
	Hamstring strength		= (18)	Limited
	Hamstring-to-quadriceps ratio		= (18)	Limited

[a]LEFS, Lower Extremity Functional Scale.
[b]Effect of the intervention: =, outcome does not differ between A and D or between R and P; d, outcome favors delayed repair; *not statistically tested.
[c]Moderate evidence: provided by 1 high-quality study and/or 2 or more low-quality studies and by generally consistent findings in all studies (≥75% of the studies reported consistent findings). Limited evidence: provided by only 1 low-quality study.

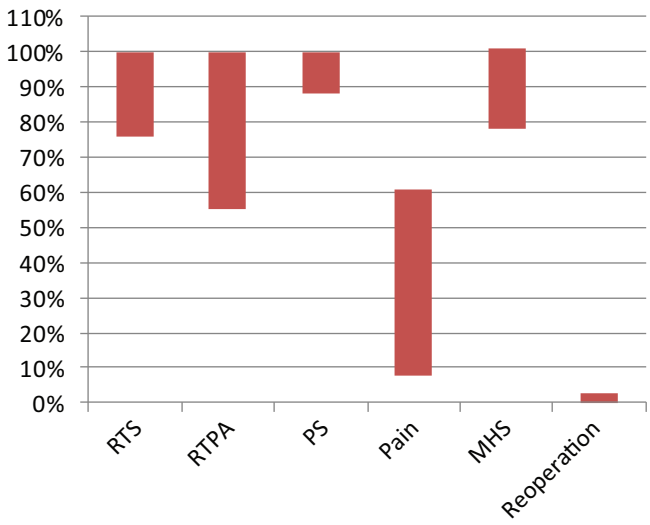

Figure 2. Reported outcome measures (range in %) after surgical repair of proximal hamstring avulsion. MHS, mean hamstring strength; PS, patient satisfaction; RTPA, return to preinjury activity level; RTS, return to sports.

Pain. Residual symptoms of pain were identical for patients in both the acute (20%) and delayed repair (20%) groups.[18]

Functional Outcome Scales. The LEFS and Marx activity scale scores were compared between acute and delayed repair groups.[11] Comparing the acute repair group with the delayed repair group, the LEFS scores averaged 76 (range, 62-80) and 72 (range, 50-80) (P = .2), respectively, and Marx activity scale scores averaged 10 (range, 1-16) and 10 (range, 2-16) (P = .6). Thus, no significant difference was found between acute and delayed repair. On the other hand, results on the custom Marx scale designed by the authors to be more hamstring specific were significantly higher in the acute repair group (20 for all participants) than in the delayed repair group (19; range, 12-20) (P = .001). Their mean custom LEFS score was not significantly different between the acute repair group (71; range, 48-80) and the delayed repair group (71; range, 47-80) (P = .7). In the study by Sarimo et al,[46] a 4-category system based on residual symptoms and postinjury level of activity was used to evaluate the results of surgical treatment. Unfortunately, this study did not use the same definition of acute and delayed surgery as we did but divided patients into 3 groups: 0- to 3-month delay from injury to surgery, 3- to 6-month delay, and >6-month delay. They found that patients with good to excellent results had shorter delays to surgery (mean, 2.4 months) than did patients with moderate to poor results (mean, 12 months) (P < .001). They reported a significant difference in results between the 0- to 3-month delay group and the 3- to 6-month (P = .004) and >6-month (P = .009) delay groups. No significant differences were found between the 3- to 6-month delay group and the >6-month delay group.

Strength Testing. Hamstring muscle strength was compared between the acute and delayed repair group in 4 studies.[4,5,18,54] No significant difference was found in isokinetic hamstring strength between acute and delayed repair.[4,5,18] Folsom and Larson[18] reported mean hamstring strength deficits of 17% (concentric 60 deg/s) and 12% (concentric 180 deg/s) in the acute repair group and deficits of 21% (concentric 60 deg/s) and 2% (concentric 180 deg/s) in the delayed repair group (P = .3). Birmingham et al[4] and Brucker et al[5] did not report separate data for acute and

delayed repair groups. The difference in isotonic hamstring strength (91% ± 4.8% vs 77% ± 5.7%, $P = .009$) and endurance (100% ± 8.5% vs 80% ± 13, $P = .04$) between acute and delayed repair (<3 or ≥3 months in this study) was significant only in cases of complete avulsion with retraction.[54]

Complications. Three studies reported (some of the) complications separately for acute and delayed repairs.[4,11,18] Cohen et al[11] reported "neuralgia" symptoms in 45% in the acute group and 58% in the delayed group. Birmingham et al[4] reported that all patients with symptoms of sciatica underwent delayed repair. Conversely, all complications reported by Folsom and Larson[18] occurred in the acute repair group (1 reoperation, 1 complex regional pain syndrome, 1 deep infection, and 5 superficial infections).

Outcome After Repair With Alternative Surgical Techniques

All studies treated most if not all avulsions with the use of suture anchors. Only 3 studies used an alternative technique[18,33,46] (Table 4). These included direct reattachment of the tendon stump to the proximal tendon stump,[33] an iliotibial tract autograft reconstruction,[46] and an Achilles tendon allograft reconstruction[18] to either augment the reconstruction or span a defect that made primary repair impossible. In the studies by Sarimo et al[46] and Lempainen et al,[33] no distinction was made between results of primary repair with suture anchors and the alternative technique. In the study by Folsom and Larson,[18] 4 of 5 delayed repairs were performed with an Achilles tendon allograft reconstruction. In the delayed group, they reported 100% patient satisfaction and return to sports rate of 80%, comparable with acute repairs with suture anchors (95% patient satisfaction and 75% return to sports rate). There was no significant difference in hamstring flexibility, hamstring-to-quadriceps ratio, isokinetic strength, and reported pain of the acute repair group compared with the delayed repair group. Note that in this particular study, no clear distinction was made in the delayed repair group between results of the allograft reconstruction (4/5) and the delayed repair with suture anchors (1/5).

DISCUSSION

This systematic review shows that all studies included are of low methodological quality. Acute and delayed surgical repair of proximal hamstring avulsions appears to result in a comparably subjective highly satisfying outcome. However, decreases in level of activity and strength, as well as symptoms of residual pain, are frequently reported. Limited evidence suggests that an Achilles allograft reconstruction yields comparable results to delayed primary repair in cases where primary repair is not possible.

Overview of Surgical Repair

A previous systematic review done by Harris et al[22] reported a return to sports rate at a preinjury level of 82% following surgical repair but did not report data concerning hamstring strength, patient satisfaction rates, and functional outcome scales, which prevents further comparison. For comparison, Sallay et al[44] and Malliaropoulos et al[36] reported return to sports rates after nonoperative management of 58% and 100%, respectively. Studies included in our systematic review reported that surgical management of proximal hamstring avulsions leads to varying rates of return to sport (76%-100%) and return to preinjury activity level (55%-100%), high scores on functional outcome scales, and high patient satisfaction (88%-100%). Reported mean hamstring muscle strength ranged from 78% to 101% compared with the unaffected side. Residual symptoms of pain during daily life, activity, or (prolonged) sitting were reported by 8% to 61%. Surgical complications such as rerupture and other major complications (deep vein thrombosis, wound infection, postoperative hematoma, and symptoms of stiffness or numbness/tingling) were uncommon.

This systematic review shows that high-quality studies are lacking. All studies scored "no" on points 2 to 7 of the PEDro scale.

We found no to minimal differences in outcome between acute and delayed repairs, with equal percentages of reported pain and even higher rates of return to sports and patient satisfaction in the delayed than in the acute repair group. Hamstring muscle strength was not significantly different between acute and delayed repairs,[4,5,18,54] unless there was a significant degree of retraction.[54] Functional outcome scales were not significantly different for acute and delayed repairs except for the (nonvalidated) custom Marx Activity Scale,[11] which was significantly higher for acute repairs. Sarimo et al[46] used a nonvalidated 4-category system based on residual symptoms and postinjury level of activity and reported a significant difference in results between the 0- to 3-month delay and >3-month delay. There were relatively more cases of postoperative neuralgia and "sciatica" in the delayed repair groups,[4,11] which, in the case of "sciatica" symptoms, is thought to be related to the increased difficulty of neurolysis in delayed repairs.[4] Conversely, all complications reported by Folsom and Larson[18] occurred after acute repairs. In contrast, in their systematic review, Harris et al[22] reported that acute surgical repair leads to better results than delayed repair in terms of subjective clinical outcomes, strength, endurance, and return to sports at the preinjury level. This difference may be attributable to differences in included studies, easily leading to different results due to the scarcity of comparative studies regarding the timing of surgery and small sample sizes. While only small outcome differences between acute and delayed repair are reported, there seems to be consensus that delayed repair is technically more challenging. This is probably caused by extensive scar tissue formation near the sciatic nerve,[4,18,26,33,44,46,54] often requiring larger incisions, more dissection, and even fractional lengthening or reconstruction.[18]

Overview of Surgical Technique

There is considerable variety in surgical techniques reported. The studies identified were used to create an overview of these variations. Patients undergoing surgery

for a proximal hamstring avulsion are typically placed in a prone position. Most authors use a longitudinal incision starting at the gluteal crease, which is extended distally.[††] Some authors advocate a transverse incision in the gluteal crease for improved cosmetic results.[1,8,11] Yet others choose the type of incision based on the extent of the injury and the timing of surgery. Typically, a transverse incision is chosen, unless there is significant retraction or surgery is considered technically more challenging due to development of adhesions if surgery is delayed, in which case a longitudinal incision or a combination of a transverse and longitudinal incision is made for better exposure.[‡‡]

Since the sciatic nerve can become trapped in the adhesions that can develop in cases with delayed repair leading to sciatic symptoms, neurolysis may be required for symptom relief and to prevent iatrogenic injury during surgery.[§§]

Reattachment of the avulsed tendon should be performed at the correct anatomic site[52] and is mainly achieved by placement of suture anchors into a debrided ischial tuberosity to which the tendons are secured. Debridement of the ischial tuberosity (removing devitalized tissue) is performed to create a bleeding cancellous bed to augment healing. The number of anchors used as well as the configuration of the suture anchors in the bone varies. A few articles have described reattachment without suture anchors.[9,13,33] In some of these cases, the avulsed tendon was sutured directly to the proximal tendon stump.

Allografts (Achilles tendon) or autografts (such as fascia lata) can be used to augment a primary repair or to span a defect caused by chronic retraction of a tendon that prevents proper reattachment.[1,6,18,30,34,37,39] Alternatively, distal fractional lengthening is also reported to facilitate repair in these cases.[25,44]

Endoscopic repair of hamstring avulsions also has been reported.[15,16] Two working portals are initially created in or near the gluteal crease. Additional portals can be added for anchor placement. The subgluteal space is cleared of scar tissue. Identification and mobilization of the sciatic nerve follow to protect it during the procedure. Neurolysis is performed if necessary. Similar to open repair, the ischial tuberosity is debrided in preparation of reattachment with suture anchors.

Both the longitudinal and transverse incision mentioned above are also used in surgical treatment of bony avulsions.[20,42,47] However, some authors use a "Kocher-Langenbeck-type" approach[19,41,48] to provide visualization of the posterior acetabular column. The avulsed apophysis is cleared of fibrous tissue and consequently reduced and refixated with plates,[48] (cancellous) screws,[20,42,47] or both.[19,41] Bone graft may be used to augment the repair.[19]

Three studies used alternative techniques (instead of primary repair with suture anchors) to achieve reattachment.[18,33,46] According to Folsom and Larson,[18] 4 of 5 delayed repairs were performed with an Achilles allograft reconstruction, leading to good rates of patient satisfaction and return to sports, comparable with those in the acute repair group (all primary repairs with suture anchors). It is conceivable that an Achilles allograft reconstruction is a suitable alternative technique in (delayed) cases where a significant degree of retraction prevents anatomic reinsertion. However, further studies are required to be able to draw solid conclusions.

Limitations and Strengths

The low quality of included studies is a major limitation. The quality assessment indicates substantial risk of selection bias due to lack of randomization and blinding in all included studies. Another major limitation is the use of nonvalidated questionnaires and grading systems. Although validated, it has been suggested that the Lower Extremity Functional Scale score[3] and the Harris hip score scale might not be effective as outcome measures for this type of injury due to unacceptably high ceiling effects.

Rather than a quantitative analysis (meta-analysis), we chose to perform a qualitative analysis because of the heterogeneity of outcome measures used, which can be considered a limitation. Also, there is great heterogeneity in study population (age, sex, level and type of sports), type of injury (partial or complete), outcome measures, rehabilitation programs, duration of follow-up, and variability in surgical technique. This may also be attributable to our search since we performed a sensitive search rather than further specify a study population and outcome measures. If results were reported for more than one point in time during follow-up, values of the last recorded follow-up were used, leading to considerable range in length of follow-up at which results were reported by the included studies. Unfortunately, studies comparing acute and delayed repair are scarce, which is even more so the case for alternative surgical techniques. With this paucity of available literature in mind, one must therefore be critical when drawing conclusions regarding timing of surgery or surgical techniques.

The strengths of this review are the thorough selection, in-depth analysis, and quality assessment of the included studies. Although the PEDro scale is a tool to assess the quality of randomized controlled trials, it particularly shows where the risk of bias lies. Rather than supporting the conclusion that acute surgical repair is undoubtedly indicated in case of a proximal hamstring avulsion, it stresses the need for further high-level comparative studies to give better insight in the indications for surgical repair and prognostic factors.

Future Perspective

Outcome after nonoperative management of proximal hamstring avulsions has not been well established. Although it has been associated with poor outcomes, especially in complete proximal avulsions,[45] there are no comparative prospective (randomized) trials to confirm this. Furthermore, nonoperative management of partial and complete proximal avulsions has recently been reported to lead to acceptable results in high-level athletes.[36]

[††]References 4, 9, 13, 18, 28, 31-34, 37, 39, 46, 51.

[‡‡]References 2, 5-7, 12, 25, 26, 31, 40, 43, 44, 49.

[§§]References 1, 4, 5-7, 9, 11, 13, 18, 19, 25, 26, 28-34, 37, 39, 43, 44, 46, 48, 51.

Future high-level prospective studies are needed to accurately assess the outcome after both nonoperative and surgical treatment of proximal hamstring avulsions. The PEDro scale revealed where the risk of bias lies in the included studies, and so future studies should at least include proper controls and randomization with blinding if feasible. Very few studies compare acute and delayed repairs, and even fewer studies compare surgical techniques. Therefore, the need for further high-level comparative studies also applies to timing of surgery and different surgical techniques.

CONCLUSION

The included studies report that surgical repair of proximal hamstring avulsions leads to a subjective highly satisfying outcome. However, it appears that both function (mean hamstring strength of 78%-101% compared with the contralateral leg) and level of activity are not fully restored in all cases (return to sports rate of 76%-100% and return to preinjury activity level rate of 55%-100%). In addition, a relevant number of participants report symptoms of residual pain (8%-61%). We found minimal to no differences in outcome of acute and delayed repairs with equivalent satisfaction, pain, functional scale scores, and strength/flexibility. It appears that an Achilles allograft reconstruction is a suitable alternative to primary repair in delayed cases where primary repair is not possible. Evidence is limited to low-quality studies, and further high-level studies are needed to accurately assess outcome after surgical repair of proximal hamstring avulsions.

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